

# Recreation Embedded State Tuning for Optimal Readiness and Effectiveness (RESTORE)

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## Abstract

Physiological self-regulation training is a behavioral medicine intervention that has demonstrated capability to improve psychophysiological coping responses to stressful experiences and to foster optimal behavioral and cognitive performance. Once developed, these psychophysiological skills require regular practice for maintenance. A concomitant benefit of these physiologically monitored practice sessions is the opportunity to track crew psychophysiological responses to the challenges of the practice task in order to detect shifts in adaptability that may foretell performance degradation. Long-duration missions will include crew recreation periods that will afford physiological self-regulation training opportunities. However, to promote adherence to the regimen, the practice experience that occupies their recreation time must be perceived by the crew as engaging and entertaining throughout repeated reinforcement sessions on long-duration missions. NASA biocybernetic technologies and publications have developed a closed-loop concept that involves adjusting or modulating (cybernetic, for governing) a person's task environment based upon a comparison of that person's physiological responses (bio-) with a training or performance criterion. This approach affords the opportunity to deliver physiological self-regulation training in an entertaining and motivating fashion and can also be employed to create a conditioned association between effective performance state and task execution behaviors, while enabling tracking of individuals' psychophysiological status over time in the context of an interactive task challenge. This paper describes the aerospace spin-off technologies in this training application area as well as the current spin-back application of the technologies to long-duration missions - the Recreation Embedded State Tuning for Optimal Readiness and Effectiveness (RESTORE) concept. The RESTORE technology is designed to provide a physiological self-regulation training countermeasure for maintaining and reinforcing cognitive readiness, resilience under psychological stress, and effective mood states in long-duration crews. The technology consists of a system for delivering physiological self-regulation training and for tracking crew central and autonomic nervous system function; the system interface is designed to be experienced as engaging and entertaining throughout repeated training sessions on long-duration missions. Consequently, this self-management technology has threefold capability for recreation, behavioral health problem prophylaxis and remediation, and psychophysiological assay. The RESTORE concept aims to reduce the risk of future manned exploration missions by enhancing the capability of individual crewmembers to self-regulate cognitive states through recreation-embedded training protocols to effectively deal with the psychological toll of long-duration space flight.

## 1 RESTORE Concept Objective

The RESTORE concept is designed to be a training technology for achieving psychophysiological equanimity under stress that is embedded in individually tailored recreational activities and which will help "restore to health" space travellers in a way that is: (a) intrinsically motivating and rewarding for the space travellers to engage in, (b) targeted to help space travellers enhance their intra-personal skills for dealing with hazardous states of awareness, and (c) provide a physiologically-based monitoring capability for measuring space crew members cognitive state and functioning.

## 1.1 Relevance to Extended Space Missions

The RESTORE concept uniquely deals with three critical challenges in extended space missions: (1) the problem of deteriorating cognitive skills due to stress, monotony, high workload, and boredom; (2) training and adherence to a physiological self-regulation practice regimen designed to counter the first problem and (3) the need to remotely monitor astronaut psychophysiology and cognitive state for human error vulnerability.

### 1.1.1 *Deteriorating Cognitive and Affective State*

Advances in technology have set the stage for long-duration manned missions beyond Earth orbit. A common feature of these expeditions will be extended stays of small groups of humans in space habitats, the success of which depends on the psychological health of those crew members working continuously in confined, isolated, and hazardous environments under changing conditions of boredom and monotony, stress, and high workload.

U.S. astronaut Jerry Linenger, who spent nearly 5 months onboard *Mir*, wrote that he “was astounded at how much I had underestimated the strain of living cut off from the world in an otherworldly environment” (Linenger, 2000, p. 151). Even though he had psychologically prepared for the mission, he experienced profound feelings of confinement and isolation as well as alienation from his crewmates. The Institutes of Medicine (IOM) report, *Safe Passages* (Ball & Evans, 2001), notes that studies of Earth analogues of long-duration spaceflights show an incidence rate of behavioral health problems ranging from 3 – 13 percent per person per year. On-board unobtrusive technologies are needed as astronaut aids for detection and management of these problems. The RESTORE concept aims to reduce the risk of future manned exploration mission by increasing the capability of individual crewmembers to self-regulate cognitive states through recreation-embedded training protocols to restore effectiveness to deal with the significant stress likely to be present during long-duration space flight.

There is compelling evidence to suggest that psychological problems will be encountered by crewmembers of future space explorations. Experience with extended-duration flights longer than 100 days (about 1/10 the anticipated duration of a mission to Mars) have shown that boredom, stress, fatigue, and circadian rhythm and sleep disturbances constitute risk factors that can substantially affect mission safety and reduce human performance effectiveness. The exacting human performance requirements of such missions require that astronauts must be functioning, both cognitively and psychologically, at optimal levels. Otherwise, in the isolated confines of space, mistakes due to lack of alertness or psychological equanimity are compounded as shown by several critical incidences. For example, an exhausted Alexander Lazutkin, a Russian crewmember on *Mir* 23, mistakenly pulled a vital cable that shut down the *Mir*’s main computer, causing the station to lose power.

The report, “A Strategy for Space Biology and Medical Science” (Space Science Board, National Research Council, 1987), stated that, “it is likely that behavioral and social problems have already occurred during long-term missions and that such problems will be exacerbated as missions become more complex, as mission duration is increased, and as the composition of crews become more heterogeneous. An understanding of the problems and their amelioration is essential if man desires to occupy space for extended periods of time”. Santy (1994) further noted that, “thirty years of space flight experience in this country have yielded a gold mine of data and knowledge about the human body and its response to the space environment, but no objective data on the human psyche in that same environment has been produced --- and many scientists consider psychological issues to be the limiting factor in the human exploration of the universe”. As Astronaut John Blaha confirms, “Personally, I would not want to repeat a long-duration space flight --- and I didn’t have any emergencies. Long-duration orbital duty is much more taxing than the intense, but brief, and heady bursts of five to 14 days orbiting in the space shuttle” (Santy, 1994). A NASA Code W report (NASA Office of Inspections, Administrative Investigations, and Assessments, 1998) stated that there was a “need to improve crew and ground training in recognizing and coping with psychological stressors preflight and during flight”. RESTORE is designed to address this specific need through innovative training that will enhance crewmember capabilities to deal with the psychological stressors during extraterrestrial missions.

### 1.1.2 *Training and Adherence*

Due to the very real danger and likelihood of psychological and cognitive impairment for space crews on long-duration missions, the *Safe Passages* (2001) IOM report recommended, “developing a technology that will provide

an adequate means for assessment of the behavioral health effects of long-duration space flight and that will establish and maintain safe and productive human performance in isolated, confined, and hazardous environments....” The report further recommended that personalized individual training approaches must be incorporated and evaluated as countermeasures based on procedures for evaluation of cognitive state and functioning, that allow for self-assessment and self-management designed within a stress management context which should be combined with biofeedback and relaxation techniques.

A specific recommendation of the *Safe Passages* report was that “the effectiveness of biofeedback and other behavior coping strategies in reducing these patterns [hazardous states of awareness] and their effect on performance should also be explored”. Kanas & Manzey (2003) echo these recommendations and stated that, “crewmembers should be taught techniques pertinent to relaxation, meditation, biofeedback, and autogenic training to calm themselves in situations of high workload or tension and to lower anxious arousal by controlling autonomic functions” (p. 149). Such physiological self-regulation techniques have been used with considerable success in teaching astronauts and pilots to control autonomic and cognitive response to stressors under conditions of high workload and stress, and low task engagement and monotony (Cowings & Toscano, 2000; Prinzel, Freeman, & Pope, 2003; Kellar et al., 1993).

The IOM report, *Safe Passages* (Ball & Evans, 2001), noted that, “the role of leisure and recreational activity to combat boredom and maintain fine motor and gross motor skills has not been fully evaluated.... relaxation training and leisure activity may promote psychological well-being and improvements in coping strategies, vigilance, and performance” (p. 129). The word “recreation” is derived from the Latin, *recreare*, meaning to “restore to health”. The use of recreation time, therefore, can be utilized to help space travellers reinforce coping skills learned during ground-based training to deal with the stressors of long-duration space flight (Figure 1). Furthermore, because space travellers will be required to engage in training for extended periods of time, there is the very likely potential of being disengaged and de-motivated to complete training regimen - a common problem with traditional stress management training.



**Figure 1.** Leisure activities are an important way for the crew to counter monotony. Training embedded in recreation should be tailored for individual preferences.

RESTORE is tailor designed to be intrinsically rewarding to the individual crewmember to enhance training effectiveness and compliance through embedded recreational activities that would allow a “restoration-to-health” of space travellers psychological and cognitive functioning and reinforce learned coping capabilities for dealing with the stressors of living in outer space. Furthermore, because RESTORE utilizes virtual reality and other digital media to deliver the recreation-embedded training, such training can also be seamlessly embedded within task specific activities through virtual reality training applications. Therefore, the RESTORE training can be reinforced through the delivery of task-specific astronaut tasks which enable conditioning of stress coping responses both to generalized psychological stress, through recreation-embedded training, and to learned targeted responses to specific tasks crew members will have to perform.

### *1.1.3 Remote Psychophysiological Monitoring*

The NASA Research Announcement for Biomedical Research and Countermeasures (NASA Office of Biological and Physical Research, Biomedical Research and Countermeasures Program, 2004) specifically solicited ground-based studies for human health in space "...that will lead to development and validation of predictive tools for the assessment of psychological well-being, cognitive processing, mood, and emotion.... Also of interest are hypothesis-driven ground-based studies that would suggest and evaluate potential proactive techniques or strategies for reducing stress and improving well-being, mood, emotion, and cognitive processing in long-duration crews". The objectives of the RESTORE concept empirically address such research needs through the development of innovative recreation-embedded training technologies for enhancing crew capabilities to deal with the stressors of long-duration space flight. Furthermore, the psychophysiological monitoring capabilities of RESTORE provide ground-based objective techniques and technologies to validly and reliably identify when space travellers are experiencing distress that compromises their performance capabilities in space.

## **2 Background of RESTORE Concept**

On-board unobtrusive technologies are needed as astronaut aids for detection and management of behavioral health problems, for which studies show an incidence rate ranging from 3 – 13 percent per person per year. Physiological self-regulation training is a behavioral medicine intervention that has demonstrated capability to improve psychophysiological coping responses to stressful experiences and to foster optimal behavioral and cognitive performance. Once developed, these psychophysiological skills require regular practice for maintenance. A concomitant benefit of these physiologically monitored practice sessions is the opportunity to track crew psychophysiological responses to the challenges of the practice task in order to detect shifts in adaptability that may foretell performance degradation. Long-duration missions will include crew recreation periods that will afford physiological self-regulation training opportunities. However, to promote adherence to the regimen, the practice experience that occupies their recreation time must be perceived by crew as engaging and entertaining throughout repeated reinforcement sessions on long-duration missions.

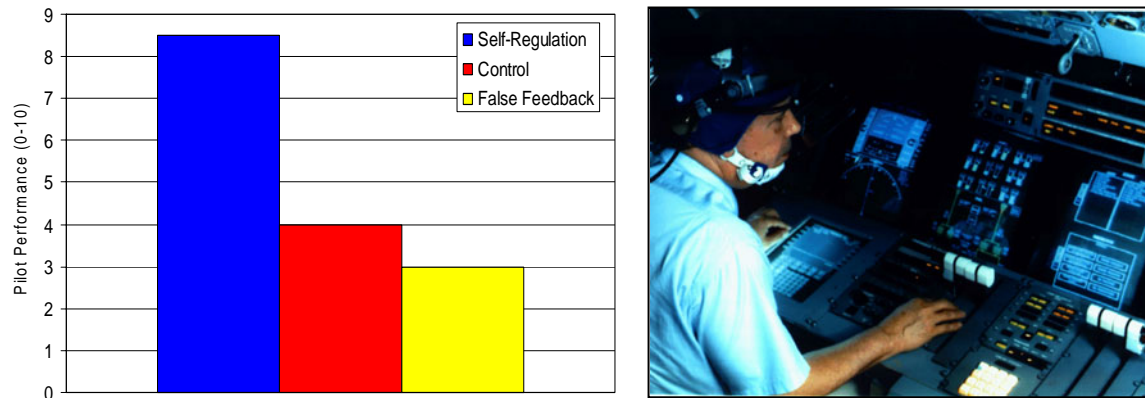
NASA biocybernetic technologies and publications have developed a closed-loop concept that involves adjusting or modulating (cybernetic, for governing) a person's task environment based upon a comparison of that person's physiological responses (bio-) with a training or performance criterion. This approach affords the opportunity to deliver physiological self-regulation training in an entertaining and motivating fashion and can also be employed to create a conditioned association between effective performance state and task execution behaviors, while enabling tracking of individuals' psychophysiological status over time in the context of an interactive task challenge.

The closed-loop concept has been implemented at NASA in a number of embodiments: 1) a real-time adaptive automation paradigm (e.g., Prinzel et al., 2000, 2001, 2004); 2) a physiological self-regulation training procedure for improved task engagement (e.g., Prinzel et al., 2002); 3) a neurofeedback system for training attentional state skills in ADHD children (e.g., NASA Office of Aerospace Technology, 2003); 4) a stress counterresponse training method (e.g., Palsson & Pope, 1999); and 5) a training system for enhancing mental state skills for sport performance (Prinzel, et al., NASA LaRC patent case no. LAR-16256). The first of these embodiments is designed to adjust the moment-to-moment human-automation interaction for more effective responsibility allocation, and it was from this research that the second application area emerged. The RESTORE concept technologies derive from the second application area, represented by the remainder of the embodiments, which are designed to train individuals to more readily achieve and maintain effective performance states (attention, mental focus, vigilance under boring conditions, equanimity or sang-froid under stressful conditions.)

### **2.1 Task Engagement Training**

Psychophysiological self-regulation training has shown promise for helping pilots deal with problems associated with the use of automation, such as automation surprises, through the enhancement of cognitive resource management skills. In a NASA study examining the use of psychophysiological self-regulation training in conjunction with adaptive automation of flight management (Prinzel et al., 2002), participants who had received self-regulation training performed significantly better and reported lower mental workload than participants in false

feedback and control groups (Figure 2). The physiological self-regulation training procedure used in this study was designed to promote task engagement and attention.



**Figure 2.** Physiological self-regulation was found to substantially enhance pilot attention and performance.

To promote adherence to a physiological self-regulation practice regimen, the practice experience that occupies their recreation time must be perceived by space crew as engaging and entertaining throughout repeated reinforcement sessions on long-duration missions. NASA has patented and licensed physiological self-regulation training technologies invented by the authors to improve adherence to a physiological self-regulation training regimen by delivering the training through engaging and motivating entertainment technologies (U.S. Patent No. 5377100, 1994; U.S. Patent No. 6450820, 2002; and 6 other invention disclosures). This approach uses physiological signals (e.g., electroencephalogram frequency band ratio) not simply to drive a biofeedback display directly, or periodically modify a task as in other systems, but to continuously modulate parameters (e.g., game character speed and mobility) of a game task in real time while the game task is being performed by other means (e.g., a game controller).

## 2.2 Neurofeedback Videogame for ADHD

A commercial videogame product based on these inventions (NASA Office of Aerospace Technology, 2003; Kharif, 2004) is currently being employed for the treatment of ADHD in the NASA licensee's network of clinical settings ([www.smartbraingames.com](http://www.smartbraingames.com)). As demonstrated in a study at Eastern Virginia Medical School (EVMS) and in current clinical practice, this recreation-embedded approach has proven effective in overcoming the problems of adherence failure and attrition that plague clinical treatment protocols that require consistent practice. In the EVMS study (Palsson et al., 2001), the video game biofeedback technology produced equivalent results to standard neurofeedback in effects on ADHD problems. Both the video game and standard neurofeedback improved the functioning of children with ADHD substantially in addition to the benefits of medication. However, the video game technology provided advantages over standard neurofeedback treatment in terms of enjoyability for the children and positive parent perception and substantially increased adherence to the practice regimen.

The video game physiological training method is inherently motivating because it blends physiological training into popular entertainment in such subtle ways that the entertainment value is not lost and training is no longer a chore but a treat. The video game or task challenge format motivates trainees to participate in and adhere to the training process through the rewards inherent in mastery of popular video games, and without the demand, monotony or frustration potential of direct concentration on physiological signals. The modulation method employed in this technology explicitly sets up physiological performance criteria, in addition to the usual hand-eye coordination criteria, for success in playing a video game. For producing particular physiological patterns, the player is explicitly rewarded by improved capability and performance in playing the game, that is, production of these physiological patterns is reinforced. In the brainwave study, improved cognitive skills and behavior accompanied these changes. The reinforcement principle involved in this process is known as the Premack prepotent principle, which is stated: "A high probability behavior may be used as the reinforcer for a low probability behavior" (Premack, 1965). A high probability behavior may be understood as that activity in which an individual will engage in the given situation, if



unconstrained (for example, video game playing.) The “low probability behavior” in this case is production of target physiological patterns.



Figure 3. Adaptive physiological training has been shown to enhance the attention of children and adults through a variety of recreational activities, such as playing video games (Left Figure), or playing a sports activity using the ZONE technology (Right Figure).

The RESTORE concept exploits additional NASA inventions to expand the application of the NASA unique physiological modulation technology beyond the licensed product into a variety of recreation devices in order to offer practice choices to trainees (Figure 3).

## 2.3 Mental State Skill Training for Sports

A third embodiment of the closed-loop modulation concept, the Zeroing Out Negative Effects (ZONE) technology (Prinzel, et al., NASA LaRC patent case no. LAR-16256), integrates physiological self-regulation training into sports practice equipment to enhance mental state skills for sport performance. The ZONE technology allows an athlete to immediately see a physical, mechanical consequence of their physiological responses, and retains a high degree of ecological validity by directly embedding the training in the actual athletic task they will perform. The ZONE technology is designed to help sports performers gain command over “choking,” “blocking,” and other performance problems that are directly linked to physiological responses of emotions, stress, anxiety, and interfering psychological processes. The ZONE technology is a training method for improving athletes’ responses to stress, anxiety and loss of concentration during competition (Figure 3). The technology informs and rewards the trainee for successful attainment of an optimal target state of psychophysiological functioning through real-time changes in the sport practice equipment. These information and reward consequences take various forms, including improved configuration of the task environment (e.g., change of putting surface from moving to still), or improved functioning of a sports implement (e.g., sharper focus of a target sighting device). The technology provides real-time feedback to the athlete about how close their arousal and emotive responses are to an optimal state required to successfully perform the athletic task. The technology makes practicing the optimal mental state and executing the sport movement both part of the same practice challenge by engineering the two tasks into the same practice device.

For the RESTORE concept, the ZONE practice technology is implemented as an extension of the NASA-licensed commercial videogame modulation product. In order to comply with size and weight constraints, changes in the practice task environment in response to the trainee’s manipulation of the sports implement are presented in computer graphics rather than in a physical realization. Those personnel who choose to practice their favorite sport in their recreation time will be honing their physiological self-regulation skill at the same time with the ZONE technology.

## 2.4 Stress Counterresponse Training

A fourth training embodiment of the closed-loop modulation concept, Stress Counterresponse Training (Palsson & Pope, 1999), integrates physiological self-regulation training into the practice of mission-relevant tasks. Stress Counterresponse Training is based upon the concept of Instrument Functionality Feedback (IFF). Using the physiologically-modulated system technology (U.S. Patent No. 6450820, 2002), the method ties the requirement to maintain physiological control to the functionality of a simulator. Instrument Functionality Feedback Training is a concept for training pilots in maintaining the physiological equilibrium suited for optimal cognitive and motor performance under emergency events in an airplane cockpit. Kellar et al. (1993) cite studies to support the assertion that “Reasonable evidence exists to conclude that pilots may lose control of their aircraft as a direct result of reactive stress. The condition in which a high state of physiological arousal is accompanied by a narrowing of the focus of attention can be referred to as autonomous mode behavior. ... A number of studies have produced evidence that this type of training [physiological self-regulation training] effectively reduces arousal which affects operational efficiency in student pilots.” IFF training is a conditioning approach for reducing pilot error during demanding or unexpected events in the cockpit by teaching pilots self-regulation of excessive autonomic nervous system (ANS) reactivity during simulated flight tasks. The training method (a) adapts biofeedback methodology to train physiological balance during simulated operation of an airplane, and (b) uses graded impairment of control over the flight task to encourage the pilot to gain mastery over his/her autonomic functions. In Instrument Functionality Feedback Training, pilots are trained to minimize their autonomic deviation from baseline values while, at the same time, operating a flight simulation. This is done by making their skin conductance and hand temperature deviations from baseline impair the functionality of the aircraft controls. Trainees also receive auditory and visual cues about their autonomic deviation, and are instructed to keep these within pre-set limits to retain full control of the aircraft.

Instrument Functionality Feedback, then, means that trainees receive feedback of how their physiology is functioning through changes in the functionality of the equipment that they are operating rather than through graphs and other signal displays, the way physiological self-regulation training is usually presented. Stress Counterresponse Training can be considered a form of counterconditioning (Chance & Lieberman, 2001) in which an adaptive physiological response to a situation or stimulus is learned, through repeated pairing, to replace an original maladaptive, usually arousal, response. The best known form of counterconditioning is systematic desensitization. The approach has much in common with Meichenbaum's (1972) Stress Inoculation Training methodologies that focus on development of cognitive and relaxation coping skills for anxiety reduction, and the use of task-specific stressors that have been shown to improve performance (Meichenbaum & Deffenbacher, 1988).

For the RESTORE concept, Stress Counterresponse Training is implemented by augmenting the NASA-licensed commercial videogame modulation product with autonomic nervous system parameter measurement, or stress measures. In addition to recreational use, the technology permits the use of mission task simulations as games modulated for concurrent physiological self-regulation training. Thus, although the RESTORE concept focuses on a recreational context for the closed-loop modulation method of physiological self-regulation training, the approach is also applicable in a mission-relevant task simulation context.

### **3 Further Considerations**

An important question is addressed in the RESTORE concept because of its theoretical implications for a classically conditioned tie, or association, of state to task stimulus conditions and for its practical implications for transfer of state training to operationally relevant conditions. That question is whether the psychophysiological state fostered by engaging in training with the physiologically modulated technology differs substantially from that fostered by interacting with unmodulated tasks or games. An indication that these states may be very different - and that the difference has important effects - comes from anecdotal reports of users of the videogame biofeedback technology. Parents have reported that, prior to training, their children became stimulated and agitated while absorbed in playing a videogame, but that, after training, videogame play appeared to settle them.

In addition to the self-regulation practice opportunity offered by modulated games and simulations, playing off-the-shelf videogames by themselves has been shown to provide generalizable manual (Rosser et al., 2004) and visual selective attention (Green & Bavelier, 2003) skill benefits.

Heretofore, “smart medical system” projects for space focused on issues such as the diagnosis and treatment of emotional disorders and group conflict resolution; the RESTORE concept is focused on development of training for

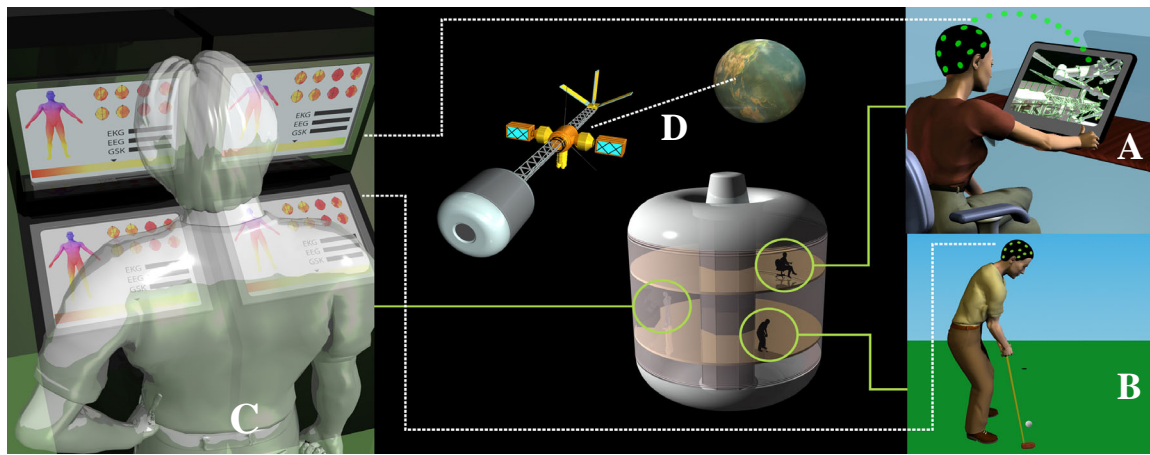
the self-management of stress-related responses and enhancement of human performance through task- and recreation-embedded physiological self-regulation training.

## 4 Summary and Conclusions

Connors et al. (1985) make the following recommendations: “Biofeedback employs instrumentation to tell the individual how well he or she is progressing in attempts at self-regulation. It would be desirable to know how these techniques could best be used, either individually or as part of an integrated therapeutic program. A common method of relieving psychological upset is to engage in distracting and rewarding activities. Although there is considerable overlap in the kinds of activities people engage in, there is also considerable individual difference. ... effort should be made to match activity options to the preferences of particular spacecrew. However, in space, activity options will necessarily be limited and space travellers will probably have to learn new distraction/relaxation techniques. We do not yet know how successful such substitutions will be.” The RESTORE concept offers an innovative approach to these issues.

RESTORE combines advanced sensors and adaptive technology with recreational activities into a behavioral health problem countermeasure technology with the following characteristics: (a) instrumentation systems for monitoring and archiving space travellers’ central and autonomic system function data; (b) instrumentation systems for supporting physiological self-regulation training to maintain and hone cognitive abilities, resilience under psychological stress, and effective mood states; (c) systems interface experienced as engaging and entertaining throughout repeated training sessions on long-duration missions; and (d) systems interface and training protocol that may be integrated with astronaut task-embedded training.

The RESTORE concept defines a physiological self-regulation training countermeasure technology for maintaining and reinforcing cognitive readiness, resilience under psychological stress, and effective mood states in long-duration crews. The technology consists of a hardware/software system for delivering physiological self-regulation training and for tracking crew central and autonomic nervous system function. RESTORE represents a self-management technology with threefold capability for recreation, behavioral health problem prophylaxis and remediation, and psychophysiological assay (Figure 4).



**Figure 4.** RESTORE is a physiological self-regulation training system that can be embedded in virtual and computer-based training tasks that the space travellers can practice to condition physiological response to actual mission tasks [A] or to virtual reality based or computer simulated recreational activities that allow the crew member to engage in recurrent practice to hone these self-regulation skills in a way that ensure practice regimen adherence [B]. RESTORE also provides for on-board real-time monitoring of physiological and cognitive state under a task challenge [C] that can be transmitted to ground-based mission control [D].



The RESTORE concept builds upon NASA published research as well as NASA patented and commercially licensed technologies to create a physiological self-regulation training countermeasure technology for maintaining and reinforcing cognitive readiness to perform, resilience under psychological stress, and effective mood states.

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